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Standardized Information Models as a base for Digital Twins

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Technology Collaboration Programme
by **iea**

Outline



- Digital Twins at PVPMC Nov 2023
- Digital Twin characteristics
- FAIR approach
- Taxonomies, Information Models, Ontologies
- Enriching Digital Twins with Semantics → Interoperability
- European Energy Data Spaces
- Vision: PV Federation of Trust

Digital Twins at PVPMC Nov 2023



The digital twin of a PV installation
How it should be

HI/ERN

- Layout / Maps the world coordinate and orientation of each element in the plant (module, inverter,...) correctly.
- Stores information for each element (BOMI) and all measurements ever performed.
- Correctly documents changes in the plant reports.
- Historic monitoring data of adequate quality
- As a rule, we do not find sufficient documentation.
- How do we get there, especially with older installations?

Collecting datasets of PV power stations for performance analysis
Claudia Buerhop
Forschungszentrum Jülich GmbH

Data-driven predictive analytics and system monitoring workflows for streamlined utility-scale photovoltaic power plant failure diagnosis, Juergen Sutterlueti Gantner Instruments

Predictive Analytics & Streamlined Data Processing

Gantner Instruments

The flowchart is divided into several stages:

- Define your Scope:** Performance Model Definition, Site Installation, Fault Detection, Performance Prediction, Data from PV, ESS, Hydrogen, Smart Grid.
- Streamlined & Extensible Stage:**
 - Data Ingestion:** Data access, APIs, Meta data access, Any resolution, Weather forecast APIs.
 - Normalization & Missing:** Unique naming convention, Normalization of parameters to error values.
 - Data Entry & Enrichment:** Data quality metrics to fill meter & PV operational data, Outlier detection & resolution.
- Digital Twin Stage:**
 - Digital Twin:** Creation of hierarchies and ML models, Definition of Training set and prediction period.
 - Performance Evaluation:** Measured vs. predicted, Error metrics and residual analysis, Weighted for Power, Energy, Meter, Real-time.
 - Performance Prediction:** Covers out-of-sample, slipping, non-recoverable faults, Real-time weather data, Forecast data.
- Evaluation Stage:**
 - Fault Signatures:** Daily profiles with labeled faults, E.g. shading, slipping, Open and short-circuit module faults, Inverter faults, and POC.
 - Fault Classifier:** Application of statistics at string, power plant level to detect performance outliers, Non-recoverable faults (long term degradation), Recoverable faults (inverter break down, operation...)

Logos for kafka, jupyter, and Airflow are shown at the bottom.

ANTICIPATE OPERATIONS & MAINTENANCE

ENERGIZING DEVELOPMENTS

EnerBIM

BIMsolar DT: the unique Digital Twin addressing BIPV O&M

The diagram illustrates the BIMsolar DT architecture, including components like BIM LODs, BIM BATCH Mode, IRRADIANCE APP, and OPTIMIZATION APP. It also shows a screenshot of a software interface with various data visualizations.

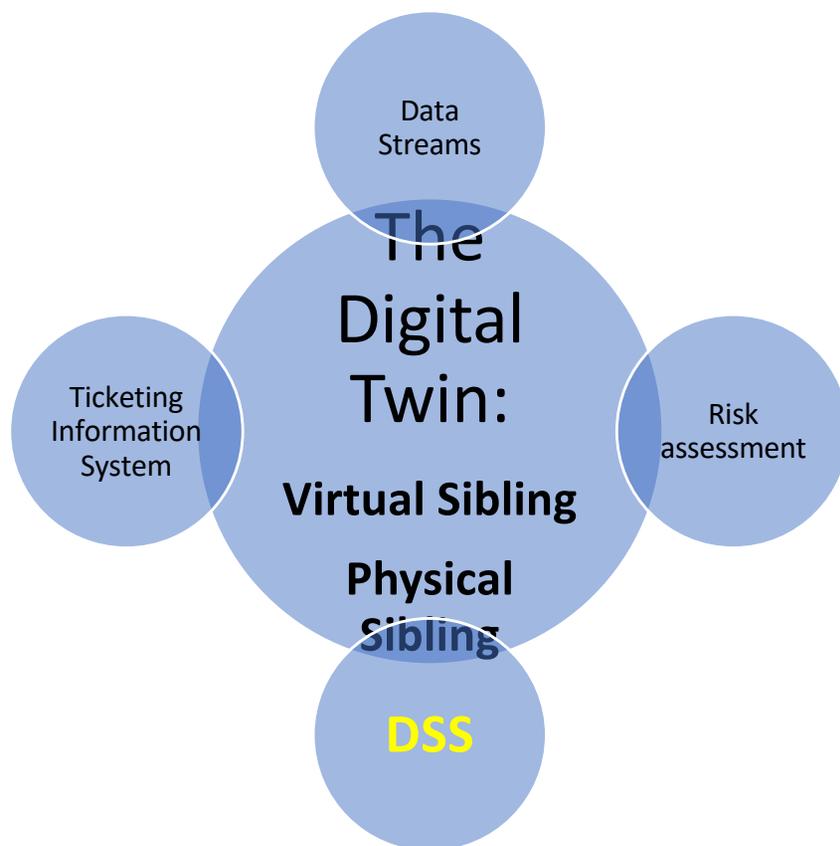
UNIQUE IDs at module level through computational analysis

Concept Design > Technical Design > Manufacturing > Installation > O&M

PVPS

BIPV Digital Twin innovations with CADCAMation
Philippe Alamy EnerBIM

Digital Twins in Photovoltaic Systems



- Enabling technologies:
 - information models, ontology/semantic models for interoperability, RDF
 - → FAIR principle
 - System simulation, phys., ML, AI
 - Monitoring and control of physical representation, IoT devices
 - Data analytics / long term data storage, Data visualization
 - Interfaces to adjacent domains (e.g. GDIs, weather/satellites etc.)

PVPS

“A digital twin is a virtual representation of a PV system that spans its lifecycle, is updated from real data, and uses simulation, machine learning and reasoning to help decision making.” ⁴

"FAIR Principles for scientific data management.." – applied to PV



- **Findable**: PV data (simulation and Monitoring), related metadata with persistent identifiers/DOIs/FDOs, → findable and citable (e.g. via CSW)
- **Accessible**: No Data Silos. PV simulation data and associated services openly accessible, clear instructions on how to access and utilize them.
- **Interoperable**
 - well-documented metadata that describes the PV simulation data, simulation methodology, input parameters, assumptions.
 - standardized data formats, information models and/or ontologies specific to the Photovoltaic domain to enhance interoperability.
- **Reusable**: proper data licensing and usage terms to enable reuse and collaboration among researchers and practitioners in the PV field (even beyond the original purpose)

Ontologies, Taxonomies, Information models



Taxonomies

- Hierarchical classification system organizing objects into categories.

Information Models

- Represent data and its structure, typically using entities, attributes, and relationships.
- Focus on capturing data structure and organization.

Ontologies

- Formal representation of knowledge, complex relationships, reasoning capabilities. Domain knowledge, logic-based formalisms

Importance of Information models for DT

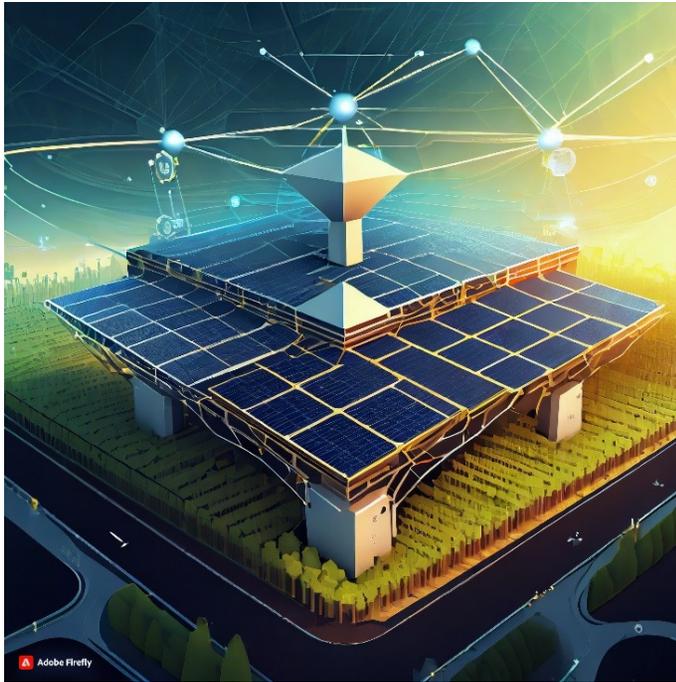


- Digital twinning involves creating a virtual representation or replica of a physical object – a PV system
- A standardized (PV-) Information Model represents the data and structure of the object or system being twinned. Consists of Entities, attributes, and relationships that define the digital twin and how it is organized.
- PV Information Model enables data management, analysis, and simulation in the context of digital twinning applications
- Ontologies are also being used in digital twinning, going a step further (machine reasoning)
- Semantics turn data into information
- Interoperability

Importance of Information models for DT



- Let's ask a generative AI to „Visualize a standardized information model for digital twins of PV systems“ 😊



Information Models, Taxonomies, Ontologies in PV



- PVML - Photovoltaic Markup Language: Toward Universal Structure for Collection and Exchange of Data Acquired During PV Monitoring Process. Prorok, M. et al, 2008
- PV-TONS: A photovoltaic technology ontology system for the design of PV-systems, Abanda et al, 2013
- OrangeButton – “open data exchange standard for the distributed solar PV industry”, Hansen et al 2018, SANDIA
- Open Energy Ontology, Booshehri et al 2021
- A Photovoltaic System Model Integrating FAIR Digital Objects and Ontologies, Schweikert et al 2023
- Proposing an Ontology Model for Planning Photovoltaic Systems, Khosrojerdi, 2021

Information Models and ontologies in PV



- CIM (Common Information Model): CIM is an information model standard used in the power system domain, including PV systems. It represents the structure and behavior of PV assets, enabling interoperability and integration with other power system components.
- For BIPV: BIM (Building Information Model), CityGML, IFC
- From OpenGeospatialConsortium (OGC): Sensor Markup Language within Sensor Web Enablement

OrangeButton taxonomy and data model



- Introduced to PVPMC in 2018
- How widely used?
- OpenAPI for RESTful services



Showcase Join Work Group How to Contribute About Blog My Account 3



Orange Button OpenAPI Editor

- VoltageDCMax
- VoltageDCMin
- VoltageDCNom
- ▣ MPPTs [MPPT]
- ▣ DCOutput
 - CurrentDCMax
 - PowerDCContinuousMax
 - PowerDCMax
 - VoltageDCMax
 - VoltageDCMin
 - VoltageDCNom
 - ▣ PowerDCPeaks [PowerDCPeak]
- ▣ DataFilterCriteria +
- ▣ DataRecord
 - DeviceID
- ▣ Device
 - Description
 - DeviceID
 - ProdCode
 - SerialNum
 - URL
 - ▣ DeviceMaintenance
 - ▣ Location
 - ▣ Orientation

Buttons: Collapse All, Create New Definition, Load In Definition, Item Types Editor

Detailed View

Create Sample JSON Save As

| Attributes | Values |
|---------------|-----------------------------|
| Name | DataFilterCriteria |
| Documentation | Documentation not available |
| Type | Object |
| Superclasses | None |
| Usage Tips | None |

Buttons: Edit definition, Create Sample JSON, Delete

Distributed

Large standard and open energy storage change between site to decrease costs

the SunSpec Alliance like you.

Community Resources

Join the work group on Tuesdays

Generate data models and define terms

Leverage open source and make contributions

Join the conversation



Developer Benefits

- Ready-to-use taxonomy and data models, 1,000's of defined terms for operational use cases
- Easy to adopt Apache 2.0 license
- Active work group that meets weekly
- Reference apps that show how its done
- Harmonization with international standards including IEEE, IEC, SAE, and SunSpec

European Commission: Digitalising the Energy System

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A European framework for sharing data to support innovative energy services

Opportunity / issue: The key enabler for a digitalised energy system is the availability of, access to, and sharing of energy-related data.

Aim: To facilitate the development of innovative energy solutions and novel and inclusive services that will support grid developments, engage consumers/prosumers and lower bills, and further the integration of the energy market.

Means: Develop a European framework for sharing energy data. Establish a **common European data space for energy**.

Approach: Harmonizing the European Data Markets in line with sector-specific legislation.



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Vision: (PV-) Federation of Trust



- Federation of Trust with authentication (e.g. Eduroam, internet2 and GEANT)
- DTs use “Simulation as a service”, e.g. also from agricultural- and other domains (APV, PV+Storage etc.)!
- PV “data as a service”
- Standardized access to information from adjacent domains (geospatial, weather, buildings, forecast etc.) via APIs
- Federated learning within data spaces
- GDPR compliant
- An “End to data silos”

Thank you for your interest!



IEA Task 13 in exchange with IEA Task 15

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